

Capturing Uncertainty in the Common Tactical/Environmental Picture

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Award Number: N00014-00-G-0450-02-1

LONG-TERM GOALS

The long-term goal of this project is to characterize the uncertainty in active sonar performance due to the environment for antisubmarine warfare (ASW). As of fiscal year 2003 (FY03), the target transition has shifted from surface to air ASW.

OBJECTIVES

Efforts in FY03 focused primarily on characterizing the statistical variability of signal excess (SE) due to environmental factors in the bottom and in the sound speed profile (SSP). We considered contributions to variability in the signal excess due to transmission loss (TL), mean reverberation level (RL), and target strength (TS). Stochastic variability in the sound speed profile was considered as the result of internal waves, while bottom variability was characterized in terms of bottom loss and bottom backscatter. The statistical model of signal excess was used to drive Metron's Likelihood Ratio Tracker (LRT), which performs Bayesian tracking for sensors modeling a sonobuoy field.

APPROACH

Our institution is part of a larger team, headed by APL/UW, that includes NRL-SSC, NRL-DC, Metron Corp., and Oregon State University. All are funded under the ONR-sponsored Capturing Uncertainty Defense Research Initiative (DRI). ARL:UT's role in the project is to provide statistical analysis and signal processing of model data provided by APL/UW and to cast this processed data into a form suitable for implementation in a Bayesian tracker. By varying the environment in a known way, we can study the impact of those variations on sonar performance and detection capability. The statistical description of the data obtained in this manner is used to construct a Bayesian likelihood distribution for the target state, which is used by Metron in its LRT.

ARL:UT has been responsible for two main components of the project: a statistical model of reverberation and transmission loss, and a broadband, bistatic model of target strength. The former were derived from Monte Carlo simulations using multiple realizations of an internal wave field in the East China Sea corresponding to the SHAREM 134 naval exercise. Transmission loss and reverberation predictions were made using the Comprehensive Acoustic System Simulation (CASS), a ray-based, Navy-standard acoustic propagation model. The resulting ensemble of TL and RL predictions were analyzed and fitted to a probabilistic model. (This work was performed with the assistance of Mr. Robert Luter of ARL:UT.)

Report Documentation Page			Form Approved OMB No. 0704-0188		
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1. REPORT DATE 30 SEP 2003	2. REPORT TYPE		3. DATES COVERED 00-00-2003 to 00-00-2003		
4. TITLE AND SUBTITLE Capturing Uncertainty in the Common Tactical/Environmental Picture			5a. CONTRACT NUMBER		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S)			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Applied Research Laboratories,,P.O. Box 8029,,Austin,,TX,78713			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

The second component of our work was the development of a bistatic target strength model. For this work, we used tools from David Drumheller's BASIS model [1], a target strength model based on pure specular reflection and the Bistatic Theorem. (This work was performed jointly with Mr. Timothy Hawkins, also of ARL:UT.) Stochastic variability in target strength was modeled by a Rician distribution, a model which we have validated by comparison with high precision, mid-frequency target strength measurements taken from ARL:UT's Target Strength Measurement System (TSMS).

WORK COMPLETED

Considering variability due to internal waves, we have performed statistical tests for normality on the empirical distributions of RL and TL and made estimates of distribution parameters. We have found that both are normally distributed to within statistical errors. The resulting distribution for signal excess has been incorporated into the Metron Bayesian likelihood ratio tracker.

In FY03 we also completed an analysis of non-Rayleigh reverberation statistics using extreme value theory. In this work we considered the extremal statistics of threshold crossings in normalized, matched-filter data. We have found that these may be characterized generally by a generalized Pareto distribution, which properly captures the power-law behavior of tails in the distribution for broadband, mid-frequency data. The results of this work have been submitted for publication. (See reference below.)

Using the BASIS model, we have constructed a realistic, bistatic model of target strength for a nuclear submarine of the sort often used in training exercises. This model was modified to provide a broadband target strength estimate by coherently summing narrow band target strength estimates. The model has now been incorporated into Metron's likelihood ratio tracker.

RESULTS

The statistical analysis of signal excess has shown that the distributions of mean reverberation levels and transmission loss with respect to internal wave fluctuations appear to be consistent with a normal distribution. The standard deviation of TL was in general much greater than that of RL. The standard deviation of RL tended to scale with the mean value, while that of TL tended to remain constant with respect to range and depth. For a realistic model of internal waves in the East China Sea, the standard deviation in signal excess due to TL and RL amounts to about 8 dB.

The target strength component of the signal excess may be modeled by a Rician distribution (in linear units) to good approximation. Target strength at higher bandwidths tends to be smoother than that of narrow band, due to the effect of averaging over multiple frequency. Variability due to fluctuations in target strength contribute a level of uncertainty comparable to that due to transmission loss.

IMPACT/APPLICATIONS

Results of this work would apply generally to the augmentation of tactical decision aids (TDAs) such as IMAT, SIMAS, SPFFS, STDA, and TCP by incorporating uncertainty estimates of predicted performance. It should also provide the basis for incorporating and displaying uncertainty in target state estimates due to uncertainty in environmental predictions such as propagation loss and sound speed. The target transition for this project is the enhancement of TDAs for air antisubmarine warfare (ASW).

RELATED PROJECTS

1. The ASIAEX experiment, performed in the South and East China Seas, has gather data in a region of the ocean overlapping that of the SHAREM 134 exercise.
2. The Geologic Clutter Initiative project aims to study the contribution of subsurface geological features to active sonar clutter.
3. ARL:UT is involved in the evaluation of target strength models under the ONR-sponsored program “Development/Validation of Broadband Target Models Using High Frequency Target Strength Measurements.”
4. Signal excess predictions and uncertainty estimates will be used in support of the Cooperative Organic Mine Defense (COMID) project funded by ONR.

REFERENCES

[1] David D. Drumheller, Mark G. Hazen, and Layton E. Gilroy, “Bistatic Acoustic Simple Integrated Structure (BASIS) Target Strength Model,” Naval Research Laboratories Report Number NRL/FR-MM/7140-02-10019, 30 May 2002.

PUBLICATIONS

Brian R. La Cour, “Statistical characterization of active sonar reverberation using extreme value theory,” *IEEE Journal of Oceanic Engineering: Special Issue on Non-Rayleigh Reverberation and Clutter*, submitted July 1, 2003.

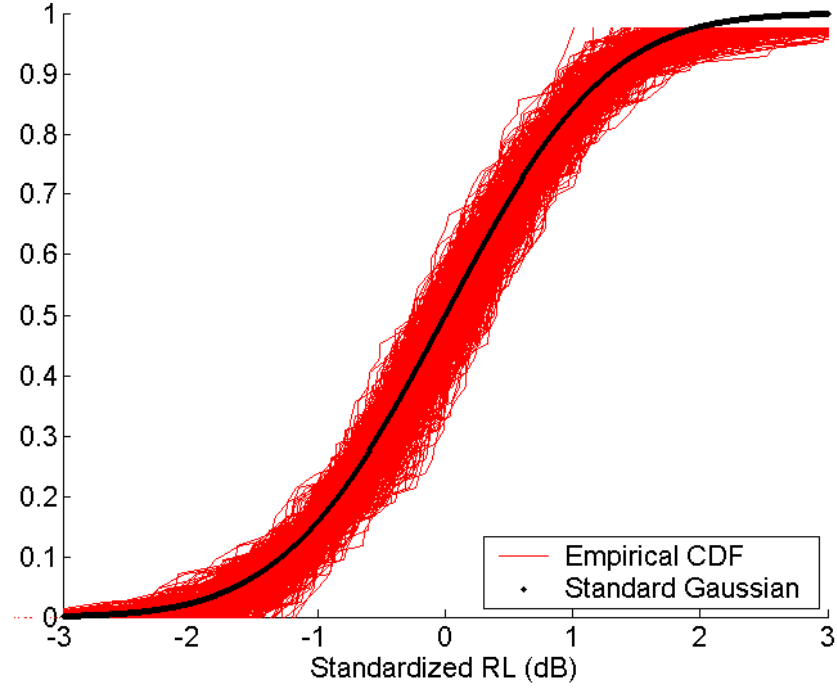


Figure 1: Statistical distribution of mean reverberation level (RL) from internal waves. The red curves correspond to a composite of numerous realizations over different internal wave fields. The black curve is the cumulative distribution function for a standard Gaussian, shown for comparison.

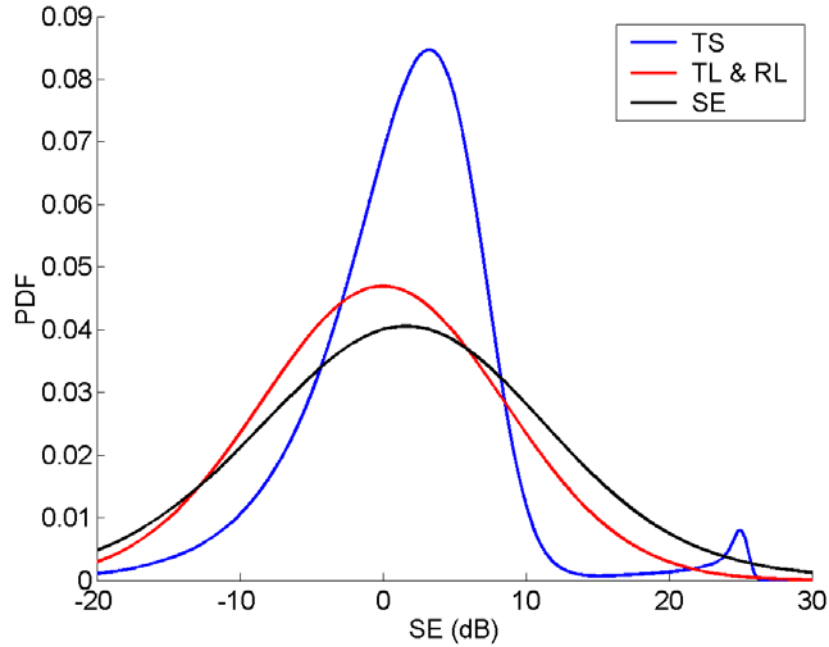


Figure 2: Plots of the probability density functions for transmission loss and reverberation (TL & RL, shown in red), bistatic target strength (TS, averaged over aspect), and the resulting signal excess (SE, shown in black). The latter is approximately Gaussian with a standard deviation of about 10 dB.